PB-215 459

NUTRIENT REMOVAL BY ADVANCED WASTE TREATMENT

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Federal Water Quality Administration
Cincinnati, Ohio

1973

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ABSTRACT

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This paper presents a review of the more promising advanced waste treatment processes or process modifications for the removal of nitrogen and phosphorus. Chemical precipitation of phosphorus in primary, secondary and tertiary treatment is discussed with regard to the relative merits and disadvantages of each point of chemical addition. Removal of ammonia by air stripping at high pH, ammonia removal by selective ion exchange, and biological nitrification-denitrification can reduce the nitrogen concentrations in wastewater to low levels.

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NUTRIENT REMOVAL BY ADVANCED WASTE TREATMENT*

James J. Westrick**

The justifiable concern over the eutrophication problems now facing those agencies responsible for environmental control has lent impetus to the search for methods of minimizing algal stimulation due to wastewater discharge. One approach has been the reduction of one or more algal nutrients in wastewater to the lowest feasible level. Of these nutrients, nitrogen and especially phosphorus have received the most attention for eutrophication control. This paper will briefly survey the more promising advanced waste treatment methods which have been or are being developed for the removal of nitrogen and phosphorus from wastewaters.

Phosphorus Removal

The most economical and reliable method of removing phosphorus in the concentrations normally encountered in wastewater is chemical precipitation. Lime or salts of iron or aluminum have been used effectively. Phosphorus may be removed by chemical addition to primary clarifiers, aeration tanks or tertiary clarifiers as shown in Fig. 1. The point of addition and the chemical used depend upon the factors shown in Table 1[1].

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*Presented at the 42nd Annual Conference of the Water Pollution Control Association of Pennsylvania, University Park, Pennsylvania, August 6, 1970.

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Precipitation with Iron or Aluminum Salts

Salts of iron or aluminum may be added to the waste stream at any of the points mentioned previously. Iron salts which may be used are ferric chloride, ferric sulfate, ferrous chloride or ferrous sulfate. Waste pickle liquor is a possible inexpensive source of iron (ferrous chloride or sulfate). The ferrous salts require the addition of a base[2] (NaOH or lime) and all iron salts may require polymer addition to aid in clarification when applied in primary or tertiary systems. Alum (aluminum sulfate) and sodium aluminate are the aluminum compounds normally considered.

The addition of metallic salts to primary clarifiers enhances the clarification and thus does double duty, i.e., increased suspended solids and BOD removal together with phosphate removal. Thus, the organic load to the secondary system is reduced with possible concomitant reduction in air supply and waste activated sludge production.

The results of full-scale phosphorus removal in existing primary plants at Grayling, Michigan, and Mentor, Ohio, are shown in Tables 2 and 3[3]. It can be seen from the data at Grayling that not only was the phosphate concentration reduced by 72 percent but significant improvements in BOD and suspended solids removal were accomplished. At Mentor a convenient supply of waste pickle liquor permitted the use of this waste material as the source of iron. Recent developments favor the use of ferric salts over ferrous salts for efficient and economical treatment.

Metal salts may be introduced directly into the aeration tank of an activated sludge system[4,5,6,7]. Any of the iron or aluminum compounds mentioned previously could be used. Adding chemicals to the aeration tank results in reduced chemical requirements compared to straight precipitation as shown in Fig. 2. This reduction is apparently due to the effect of inclusion of the metal-phosphate precipitate in the biological floc, obviating the need for excess chemicals for flocculation. Another factor favoring chemical addition to the aerator over addition to the primary is that most of the difficult polyphosphates in the raw sewage are hydrolyzed to the more easily precipitated orthophosphates in the aeration system. Also phosphate removal in the primary results in a considerable increase in the volume of primary sludge whereas combined chemical-biological phosphorus removal provides a dense waste activated sludge and no additional sludge handling facilities are required.

Data from the 2 MGD activated sludge facility at Pomona, California, are shown in Table 4[8]. Alum and aluminate were compared sequentially on this fairly alkaline wastewater. Alum performed somewhat more satisfactorily here due to the presence of sufficient alkalinity which prevented excessive reduction of pH. It should be emphasized that efficient phosphorus removal depends on effective solids removal by bio-flocculation and clarification and the chemical addition has on occasion caused upsets in the activated sludge system such that good flocculation of the metal-phosphate precipitate did not occur. This

results in decreased removal efficiency which can usually be remedied by the addition of a polymeric flocculating agent.

If very high quality effluent is required, either for discharge or reuse, tertiary treatment may be necessary. Tertiary clarification with iron or alum can provide an effluent low in phosphorus, BOD and suspended solids. An example of tertiary clarification with alum is the 400 gpm pilot study at Nassau County, New York[9,10]. The objective of this study is to determine the feasibility of treating secondary effluent to a quality suitable for ground water recharge. The processes include alum clarification, dual media filtration and adsorption on granular activated carbon. Table 5 shows preliminary results of operation of the clarification and filtration portions of the system. With an average alum dose of 200 mg/l, phosphorus was reduced to around 1 mg/l in the clarifier effluent. Polishing by filtration produced a highly clarified effluent containing less than 0.1 mg/l P. Phosphate removal is not a major objective of the project, but sufficient alum is added for effective clarification to produce very low phosphorus residuals in the filter effluent.

Phosphorus Removal by Lime Clarification

The use of lime as a phosphorus precipitant holds considerable promise, especially in tertiary treatment, principally because lime is inexpensive and can be recovered by recalcination of the sludge. Also the required lime dosage is relatively unaffected by the phosphorus concentration in the effluent, being much more dependent upon other

characteristics of the wastewater. Lime, when added to wastewater, serves to raise the pH and combine with phosphates to form insoluble calcium phosphate called hydroxyapatite. Since the solubility of hydroxyapatite decreases with increasing pH, the required lime dose is that necessary to raise the pH to the value required to reduce phosphorus to the specified level in the effluent. The amount of lime required to raise the pH to a given value is a function of the initial alkalinity of the wastewater, as illustrated in Figure 3[11]. It can be seen that wastewaters with high alkalinity (buffer capacity) necessarily require high lime doses to reach a pH range wherein phosphorus precipitation is effective. An illustration of the pH dependence of phosphorus removal by lime is shown in Fig. 4.[11] There are many intricacies involved in lime treatment beyond the scope of this review, and for more information the reader is referred to the work of Bishop and co-workers[11,12,13,14] and Mulbarger, et al[15].

Berg, et al[16] have reported on the operation of a 75 gpm pilot lime clarification and filtration system treating activated sludge effluent at the Federal Water Quality Administration pilot plant at Lebanon, Ohio. This wastewater has relatively high hardness and alkalinity. Operation at pH 9.5 resulted in an average phosphorus concentration of 0.8 mg/l and 0.6 mg/l in the clarifier and filter effluents respectively, while those phosphorus levels were reduced to 0.5 and 0.1 by operating at pH 10.7. Because of the relatively high hardness of the Lebanon wastewater, a sufficient percentage of the

sludge formed was dense calcium carbonate to permit relatively successful clarifier operation in a single stage.

The lime clarification system at the joint FWQA-DC pilot plant in Washington, D. C.[12] must be either operated as a two-stage system or as a single-stage system with the addition of carbonate as soda ash or CO_2. There is insufficient alkalinity in the D. C. wastewater to permit the formation of a dense, good settling calcium carbonate sludge with lime addition alone. The most effective treatment sequence has been two-stage treatment, i.e., lime to pH 11.5 in the first stage clarifier, reduction of pH to 9.5-10 by the addition of CO_2 and clarification in the second stage with the aid of 6-12 mg/1 Fe^{+++}. The average phosphorus residuals in the clarification and filtration effluents were 0.55 and 0.39 mg/l respectively. This amounted to 93 percent and 95 percent removals through the two-stage clarification and dual-media filtration steps, respectively. The lime dose in this operation was 290 mg/1 as CaO to reach pH 11.5. Nearly equivalent results were obtained by substituting 0.15 mg/1 of an anionic polymer for the iron flocculant as shown in Table 6.

Perhaps the most well known tertiary lime clarification system is part of the 7.5 MGD water renovation facility of the South Tahoe Public Utility District[17]. A simplified flow sheet is shown in Fig. 5. Phosphorus and suspended solids are removed from activated sludge effluent by two-stage lime clarification followed by mixed-media filtration. The solids handling system at Tahoe includes lime sludge

thickening, dewatering by centrifugation and recalcination in a multiple hearth furnace. About 75 percent of the recalcined product is reused, while the remainder must be bled off to maintain sufficient available CaO and to prevent buildup of non-carbonate solids (including phosphates) and ash. Recalcined lime appears to be as effective as virgin lime in the treatment process. The cost of recalcining the lime sludge is roughly equivalent to the cost of virgin lime, but sludge disposal costs are reduced, since only a fraction of the lime sludge must be disposed of.

It should be emphasized that sludge from lime clarification of of different wastewaters may exhibit different chemical composition, dewatering characteristics, etc., and in some cases recalcination and reuse could be uneconomical or impractical. Also, tertiary clarification efficiency and sludge quality depend a great deal upon the quality of the secondary effluent. Upsets in activated sludge systems often cause upsets in tertiary clarification, and activated sludge solids carried over to the tertiary system can impair the thickening and dewatering properties of the sludge.

There has been recent interest in lime treatment of raw sewage for clarification prior to biological treatment[18,19] or activated carbon adsorption[20,21]. It is quite possible that for lime recovery to be practical when treating raw sewage, some sort of classification of calcium carbonate from the sewage solids or calcium oxide from the ash will be necessary. The joint FWQA-DC pilot plant is currently treating raw sewage by two-stage lime clarification with intermediate carbonation

followed by dual media filtration and subsequent advanced waste treatment processes[21]. Some results taken from this study are shown in Table 7.[22] The clarification system was operated on a diurnal flow cycle averaging 100,000 gpd. A lime dose of 350-400 mg/l CaO was used to maintain the pH at 11.8. The pH was subsequently reduced to 10.0 by carbonation. It can be seen from the results listed in Table 7 that not only does effective lime clarification reduce phosphorus and suspended solids, but a significant organic reduction is also accomplished. Excessive biological growth appeared in the dual media filters shortening the length of filter run considerably. The situation was corrected by chlorination. The recalcination system has not been operated a sufficient period of time for any inferences to be made concerning the influence of sewage solids.

Nitrogen Removal

Advanced waste treatment processes and process modifications for the removal of nitrogenous compounds from wastewater have not been developed as thoroughly or as rapidly as phosphorus removal processes, but some have been tested on small or large-scale applications. Among those nitrogen removal processes showing the most promise are biological nitrification-denitrification, ammonia stripping, and selective ion exchange.

Biological Nitrification-Denitrification

Nitrogen removal by biological processes depends on the conversion of organic and ammonia nitrogen to the nitrate form and subsequent

reduction of the nitrate nitrogen to elemental nitrogen, which is released to the atmosphere as nitrogen gas. Since nitrification in conventional activated sludge systems is not consistent or easily controlled, the concept of separate sludge systems for the three functions of the process has been put forward[6]. This concept is shown schematically in Fig. 6. The first stage high-rate activated sludge system removes the major fraction of the carbonaceous materials. Effluent from the first stage is introduced into a nitrification system, where conditions are conducive to the development of a nitrifying population.

Since most of the carbonaceous material has been utilized in the first stage, biological oxidation of ammonia to nitrate takes place readily and consistently. Nitrified effluent is then discharged into the denitrification system. There is little biodegradable organic carbon remaining in the nitrified effluent, therefore methyl alcohol is added to supply a carbon source. The bacteria then utilize oxygen from the nitrate nitrogen to release nitrogen gas. There is little or no cell synthesis in the nitrification and denitrification systems, therefore sludge wasting from those systems is minimal. Nearly all the waste sludge is derived from the high rate - high synthesis first stage.

This three-sludge system was tested in a 185 gpd continuous flow pilot plant at R. A. Taft Water Research Center in conjunction with aluminum addition to the first stage for phosphorus removal as

shown in Fig. 7 [6]. The average concentrations of various constituents of interest are shown in Table 8. It can be seen that total nitrogen was reduced from 21.6 mg/l to 1.9 mg/l or 91 percent. The required methanol to nitrate-N ratio was 4:1 by weight.

Further studies are underway at the Manassas, Virginia, Field Station of Federal Water Quality Administration to further refine the biological nitrification-denitrification process on a larger scale, including combination of two or more of the various sludge systems.[23]

Packed bed columns can be used to denitrify a nitrified sewage effluent, i.e., the third stage system as illustrated above can be replaced with a column containing media such as sand or gravel. Data taken at the FWQA pilot plant facility at Lebanon[24] indicate that 90 percent nitrate reduction can be achieved in short contact times (10-30 minutes, empty bed) with lower methanol requirement (3:1 methanol: nitrate N on a weight basis) than the activated sludge type denitrification systems. It has also been determined that denitrification can take place in the presence of 1-2 mg/l of dissolved oxygen.

Ammonia Stripping

The nitrogen in the effluent from most waste treatment facilities exists primarily as ammonium ion. If the pH of the wastewater is increased to a very high level (> pH 11) the ammonium ion is converted to dissolved ammonia gas. Although ammonia is quite soluble, it can be desorbed or stripped by contacting the high pH wastewater with large volumes of ammonia-free air. Since lime clarification can be carried

out at a pH high enough to convert most or all the ammonium ion to dissolved ammonia, this method of phosphorus removal lends itself to subsequent ammonia removal by air stripping. This method of nitrogen removal is in fact being practiced at the South Tahoe facility[17]. After first-stage lime clarification at pH 11.5, the wastewater is passed through a cross-flow cooling tower where it is contacted with about 400 cu ft of air per gallon of wastewater. Because ammonia solubility increases with decreasing temperature, much more air is required for cold weather stripping, and temperatures below freezing render the stripping tower inoperable or require the addition of supplemental heat.

A pilot ammonia stripping tower has been operated at the joint FWQA-DC pilot plant following first-stage lime clarification at pH 11.8-12.0 [13]. A schematic of the countercurrent-crossflow pilot tower is shown in Fig. 8. Continuous operation at 32 gpm resulted in a decrease in ammonia removal efficiency from 80 percent to 55 percent over a period of 75 days as illustrated in Fig. 9. A small fraction of this decrease was the result of a decline in ambient temperature over the period and is represented by the dashed line. However, the remainder of the loss in efficiency was charged to the decrease in air flow from an initial value of 350 cu ft/gal to 250 cu ft/gal at the end of the study period. Following the end of continuous operation, the tower was dismantled and found to have accumulated 2 tons of calcium carbonate scale on the packing grids, resulting from contacting the unstable effluent from the first stage clarifier with the carbon dioxide in the air. This amounted to

125 mg/l of calcium carbonate scale, based on total throughput. The scale could not be removed by a high pressure water jet and the grids had to be cleaned manually. The Tahoe installation has also experienced a build-up of scale on the tower packing, but this was soft and could be hosed off. Future operations at Blue Plains will determine whether the scale problem can be minimized or eliminated. Ammonia stripping on a large scale does not appear overly promising considering the enormous volumes of air required. Air pollution problems resulting from ammonia stripping operations should be investigated.

Ammonia Removal by Selective Ion Exchange

Ammonia nitrogen can be removed from wastewater by ion exchange using an ammonium selective zeolite, clinoptilolite. Results of a 100,000 gpd pilot plant project utilizing ion exchange for removal of ammonia from secondary effluent are fairly promising[25]. A flow sheet is shown in Fig. 10. Secondary effluent from a trickling filter plant was polished by tertiary clarification-filtration and was passed through two ion exchange vessels in series containing clinoptilolite. When breakthrough of ammonia occurs in the effluent from the second column, a fresh column is put on stream and the first column is regenerated with limewater containing sodium chloride. Sodium chloride was found to enhance both the rate of exchange and regeneration. The ammonia laden regenerant solution (limewater) is then air stripped to remove the ammonia and render the limewater suitable for reuse. Continuous operation of the pilot plant at Richland, Washington, resulted in

ammonia removals of 97 and 93 percent at 70,000 and 100,000 gpd, respectively. Other methods of ultimate disposal of the ammonia from the regenerant brine are being investigated.

Summary

Phosphorus and nitrogen can be removed to desired levels by advanced waste treatment methods. Obviously, the use of these methods will add an increment of capital and operating cost. Cost estimates for the various nutrient removal methods have been purposely omitted in this report, as they involve many assumptions and can be misleading. Individual situations have requirements peculiar unto themselves; therefore investigations should be made to determine the processes which will provide the best treatment at least cost to produce the desired effluent quality. A vigorous research effort will develop additional nutrient removal schemes and refine the existing processes to a point that any community which requires and is able to pay for nutrient removal can incorporate these methods into new or existing facilities.

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TABLE 1

FACTORS AFFECTING CHOICE OF CHEMICALS

1. INFLUENT PHOSPHORUS LEVEL
2. EFFLUENT DISCHARGE STANDARD
3. WASTEWATER CHARACTERISTICS
4. PLANT SIZE
5. CHEMICAL COSTS INCLUDING TRANSPORTATION
6. SLUDGE HANDLING FACILITIES
7. SLUDGE DISPOSAL FACILITIES
8. OTHER PROCESSES UTILIZED

TABLE 2

RESULTS AT GRAYLING, MICHIGAN

CHEMICALS:

$FeCl_2$ = 15-30 mg/1 as Fe

NaOH = 30-50 mg/1 as $CaCO_3$

A-23 = 0.3-0.5 mg/1

	WITHOUT CHEMICALS (10 weeks)			WITH CHEMICALS (10 weeks)		
	Raw mg/1	Pri.Eff. mg/1	% Rem.	Raw mg/1	Pri.Eff. mg/1	% Rem.
SS	157	78	50	224	50	78
BOD	170	101	41	178	74	58
TOTAL P	No removal			15.5	4.4	72

TABLE 3

RESULTS AT MENTOR, OHIO

CHEMICALS:

WASTE PICKLE LIQUOR ($FeCl_2$)	= 43 mg/1 as Fe
LIME	= 66 mg/1
A-23	= 0.4 mg/1

PERCENT REMOVAL WITH CHEMICALS

SS	= 74%
BOD	= 59%
TOTAL P	= 83.5%

TABLE 4

POMONA DATA, AVERAGE VALUES

1968 DATE	CHEMICAL ADDED	AL:P RATIO WT./WT.	Phosphorus, mg/l			Percent Removal	
			PRIMARY EFFLUENT	FINAL EFFLUENT (UNFILTERED)	FINAL EFFLUENT (FILTERED)	UNFILTERED	FILTERED
2/12 - 2/26	ALUMINATE	1:1	13.2	2.6	2.1	80	83
2/26 - 3/11	ALUMINATE	1.5:1	13.2	2.3	0.9	83	94
3/18 - 4/1	ALUM	1.1:1	12.8	2.7	2.2	79	83
4/1 - 4/15	ALUM	1.4:1	13.5	1.4	0.7	90	95
4/15 - 4/29	ALUM	1.8:1	13.8	1.5	0.3	89	98
5/13 - 5/27	ALUMINATE	1.5:1	13.2	2.4	1.4	82	90

TABLE 5

NASSAU COUNTY OPERATING RESULTS

CONSTITUENT	INFLUENT	CLARIFIER EFFLUENT	FILTER EFFLUENT
POLYPHOSPHATE, mg/l P	0.5	-	-
TOTAL PHOSPHATE, mg/l P	7.2	1.4	0.08
TURBIDITY, JTU	50	6	0.2

TABLE 6

Plant Performance
with
Two-Stage Lime Precipitation

Process	Total Phosphorus Residual mg/l	Total Phosphorus Removal % (4)	TOC Residual mg/l	TOC Removal % (4)	Turbidity Units
No Additives (1)					
Clarification	1.00	87	19.5	45	7.7
Filtration	0.78	90	16.5	53	3.3
Carbon Adsorption			6.5	84	3.5
Ferric Chloride (2)					
Clarification	0.55	93	14.1	64	4.9
Filtration	0.39	95	10.1	74	0.5
Carbon Adsorption			2.3	95	0.4
Polymer A23 (3)					
Clarification	0.54	91	15.7	55	5.3
Filtration	0.39	94	12.9	65	2.4
Carbon Adsorption			3.2	92	1.6

(1) Rise rate 1500 gpd/ft^2; temperature 14°C; pH 11.8; length of run 50 days; lime 340 mg/l CaO

(2) Rise rate 900 gpd/ft^2; temperature 20°C; pH 11.5; length of run 56 days; lime 290 mg/l CaO; Ferric 6-12 mg/l Fe^{+++}

(3) Rise rate 1060 gpd/ft^2; temperature 23°C; pH 11.4; length of run 16 days; lime 260 mg/l CaO; Polymer 0.15 mg/l A-23 (anionic polymer by Dow Chemical Company*)

(4) Accumulated removals from secondary effluent

*Mention of a proprietary product is for identification only and does not constitute an endorsement or recommendation by the Federal Government.

TABLE 7

JOINT FWQA-D.C. PILOT PLANT
PHYSICAL-CHEMICAL TREATMENT OF RAW SEWAGE

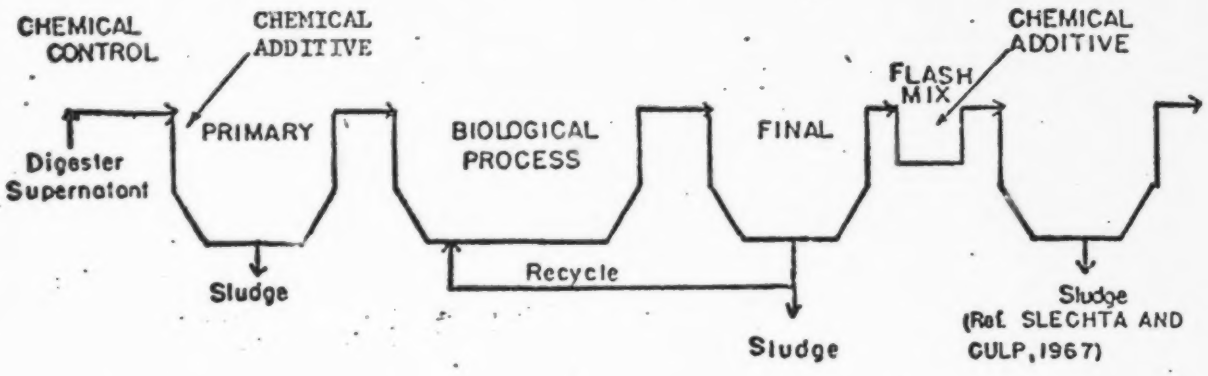
REMOVAL EFFICIENCIES

EFFLUENT	BOD		COD		SS		$PO_4^{\equiv}$	
	mg/l	% Rem	mg/l	% Rem	mg/l	% Rem	mg/l	% Rem
RAW	158	---	299	---	164	---	27.2	---
CLARIFIED	26.1	83	52.5	82.5	12	92.5	0.76	97.3
FILTERED	19.4	87.5	45.2	84.7	5.1	96.7	0.47	98.2

TABLE 8 - Change in Concentration of Various Constituents During Treatment *

Constituent	Raw waste-water mg/l	Primary effluent mg/l	High-rate effluent mg/l	Nitrified effluent mg/l	Denitrified effluent mg/l	Denitrified effluent (filtered) mg/l
COD						
Average	320	218	64	43	44	38
Range	95-1,195	67-566	24-328	17-239	21-194	15-194
Organic-N						
Average	10.3	5.9	0.8	0.4	0.4	0.2
Range	2.3-31	1.4-12	0.8-1.4	0.0-1.0	0.0-1.7	0.0-1.6
Ammonia-N						
Average	11.3	13.7	7.7	0.6	0.3	0.4
Range	0.2-24	2.5-21	0.2-16	0.0-6.0	0.0-2.2	0.0-2.3
Nitrite-N						
Average	--	--	1.1	0.3	0.3	0.4
Range	--	--	0.0-5.8	0.0-2.6	0.0-1.8	0.0-1.9
Nitrate-N						
Average	--	--	4.3	11.5	0.9	0.9
Range	--	--	0.0-10.5	3.7-24.8	0.0-7.5	0.0-6.1
Total phosphorus						
Average	12.6	11.9	2.8	2.6	1.5	1.1
Range	3.0-30	3.0-26	0.4-11.3	0.7-8.2	0.2-5.3	0.2-4.5
S.S.						
Average	157	90	8.8	7.1	7.1	1.7
Range	40-800	28-236	0.0-39	0.0-54	0.0-45	0.0-7
pH						
Mode	7.2	7.3	7.5	7.5	7.7	7.7
Range	6.7-7.6	6.9-7.6	7.2-7.8	7.1-8.0	7.2-8.0	7.0-8.3

* Each average is result of 40 determinations.



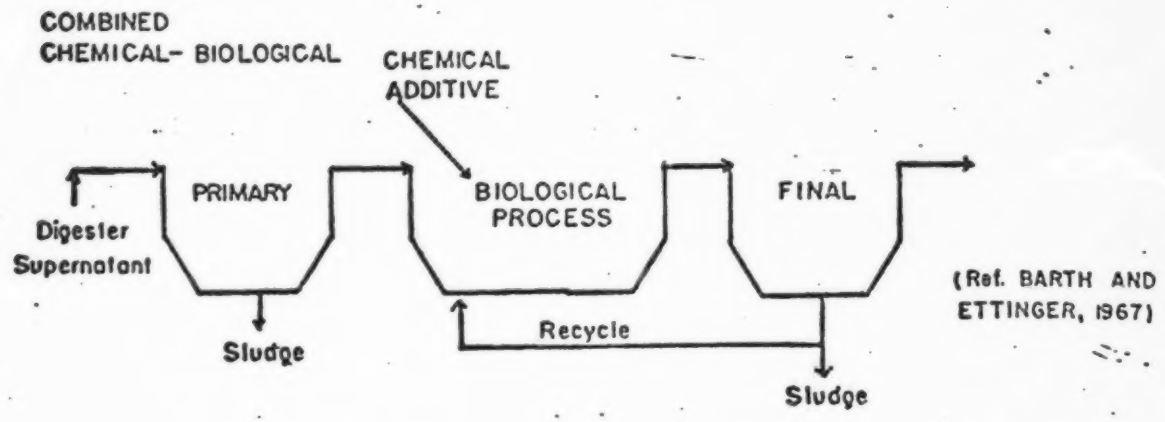
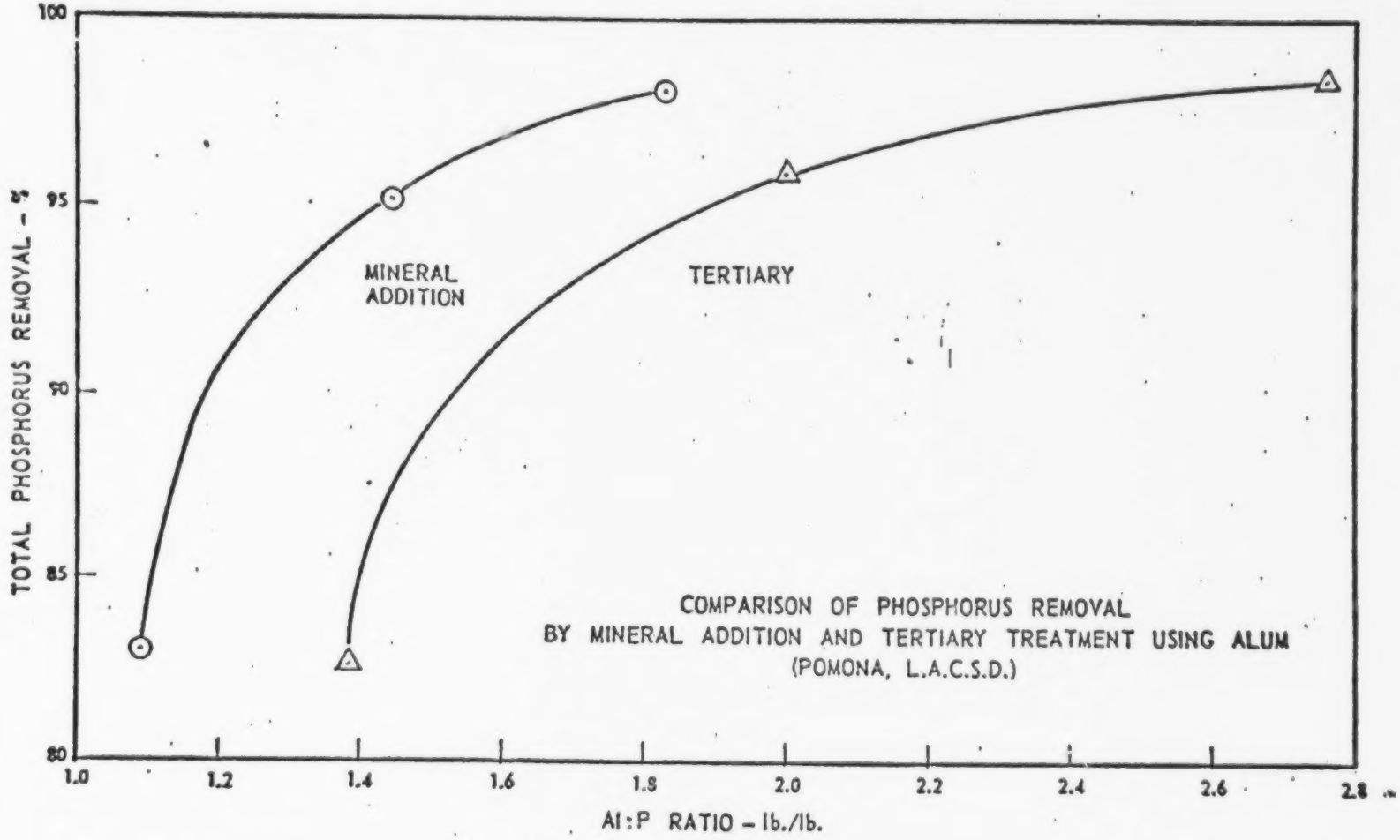


FIG. 1 PHOSPHORUS CONTROL BASIC SYSTEMS

FIGURE 2



COMPARISON OF PHOSPHORUS REMOVAL
BY MINERAL ADDITION AND TERTIARY TREATMENT USING ALUM
(POMONA, L.A.C.S.D.)

FIGURE 3

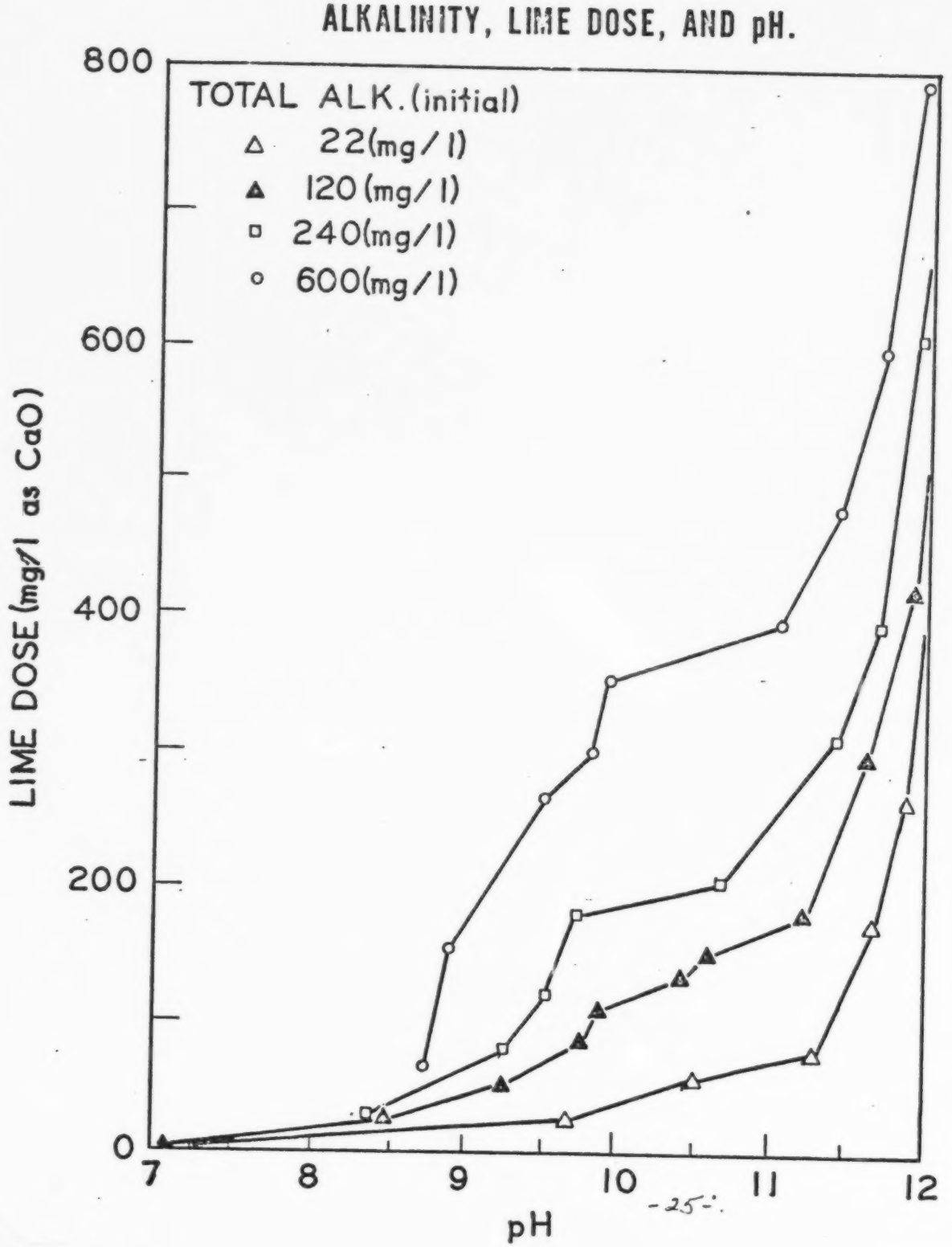
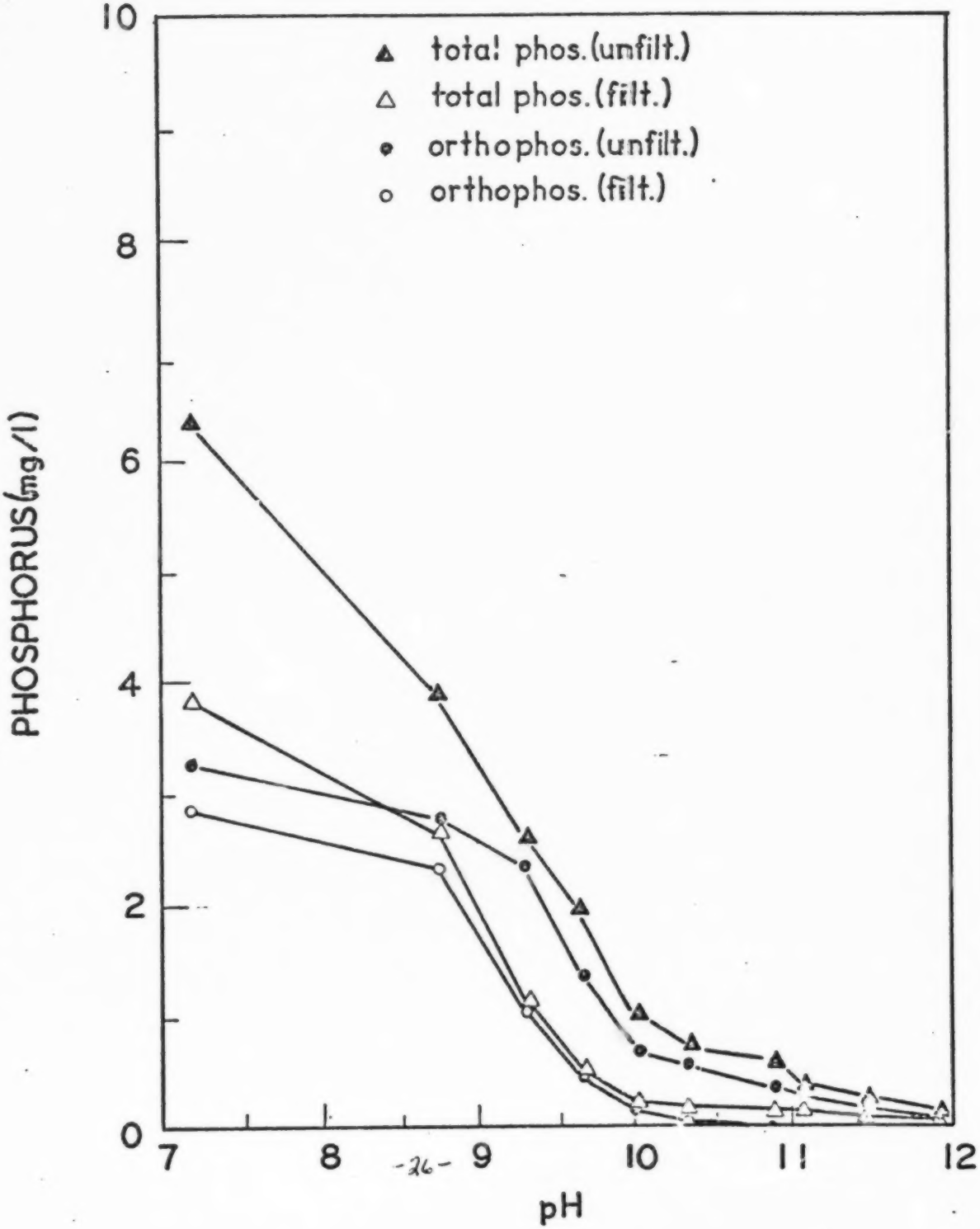

ALKALINITY, LIME DOSE, AND pH.
TOTAL ALK. (initial)
△ 22(mg/l)
▲ 120(mg/l)
□ 240(mg/l)
○ 600(mg/l)
LIME DOSE (mg/l as CaO)
800
600
400
200
0
7
8
9
10
11
12
pH

FIGURE 4

LIME PRECIPITATION AND PHOSPHORUS REMOVAL FROM RAW WASTEWATER.



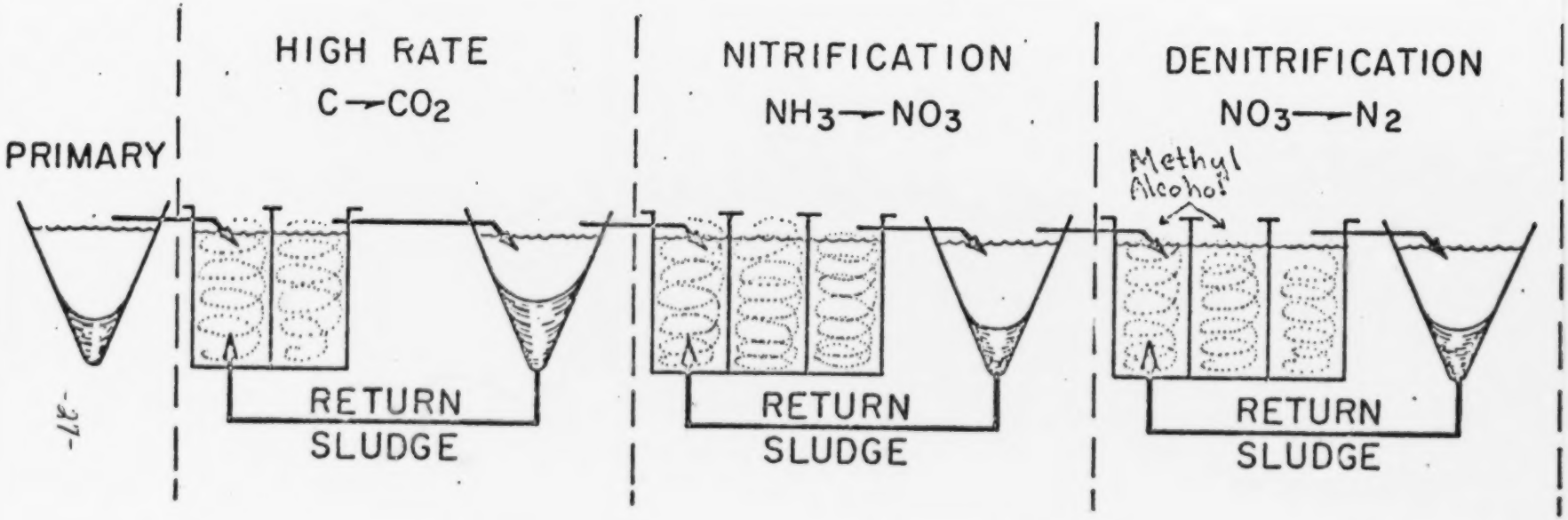
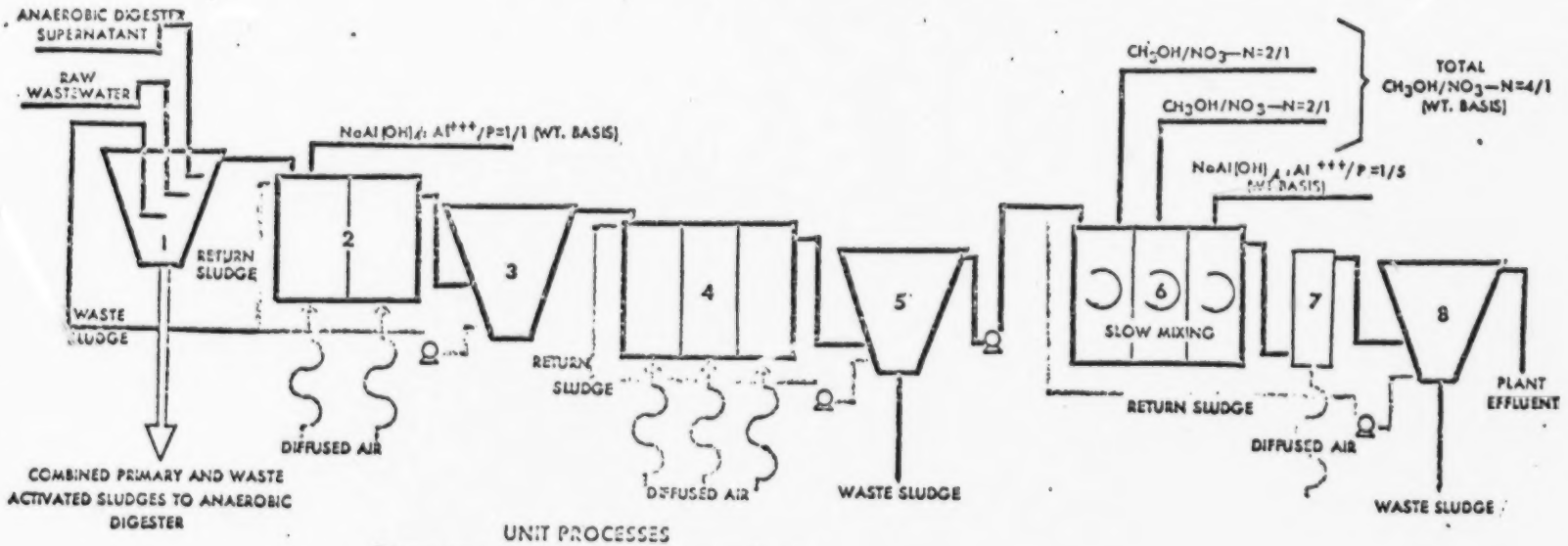


FIGURE 6

THREE SLUDGE SYSTEM FOR BIOLOGICAL NITROGEN REMOVAL

FIGURE 7

185 G.P.D. (700 LITER/DAY) WASTEWATER TREATMENT PILOT PLANT INCORPORATING NITROGEN AND PHOSPHORUS REMOVAL



UNIT PROCESSES
(Detention Time Based on Wastewater Flow)

1 PRIMARY CLARIFICATION (70 MIN.)
2 HIGH RATE ORGANIC REMOVAL (120 MIN.)
3 SECONDARY CLARIFICATION (70 MIN.)
4 NITRIFICATION (180 MIN.)
5 INTERMEDIATE CLARIFICATION (70 MIN.)
6 DENITRIFICATION -ANAEROBIC (180 MIN.)
7 FLASH AERATION (25 MIN.)
8 FINAL CLARIFICATION (70 MIN.)

FLOW RATES

RAW WASTEWATER = 500 Ml/MIN.
RETURN SLUDGE = 300 Ml/MIN.
WASTE SLUDGE (HIGH RATE UNIT) = 15—18 LITERS/DAY

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Figure 8 - AMMONIA AIR STRIPPING SYSTEM

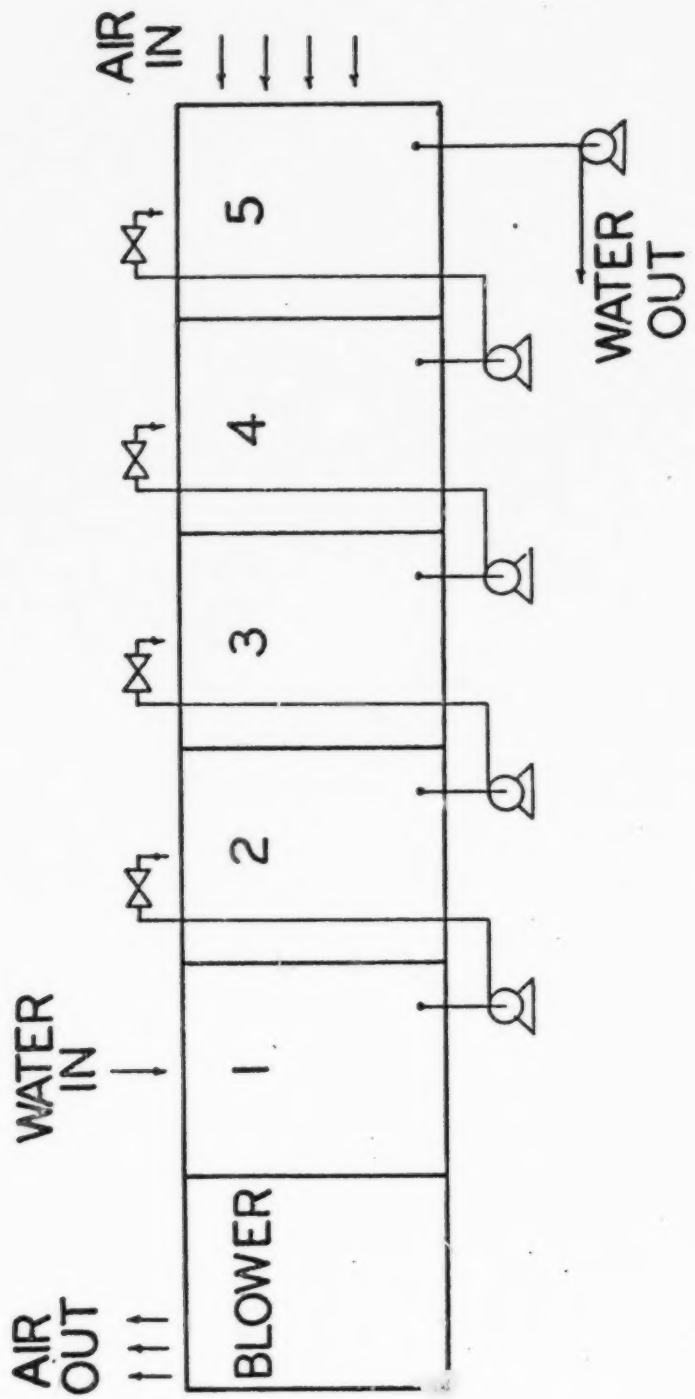


FIGURE 9. CONTINUOUS OPERATION PERFORMANCE

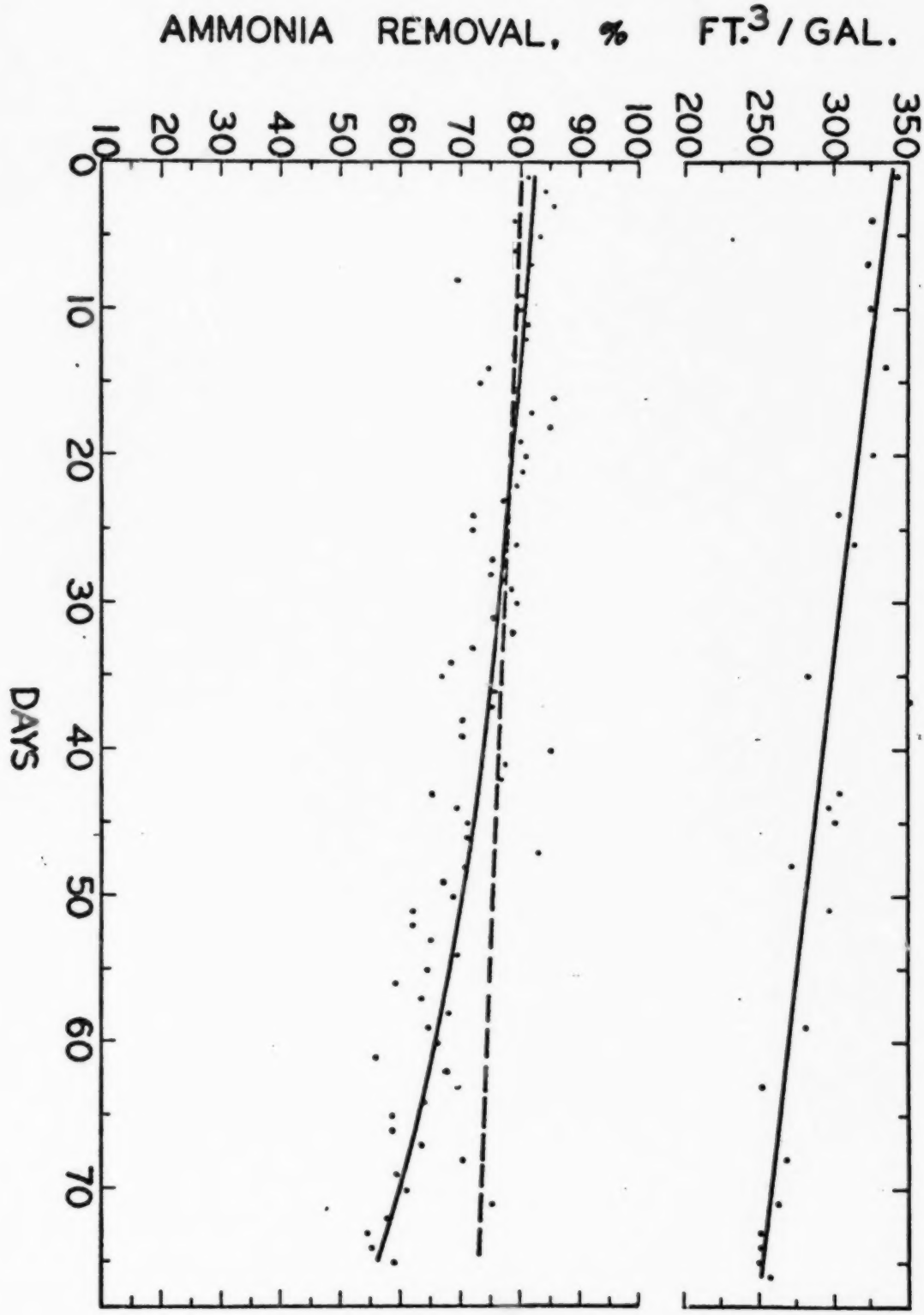
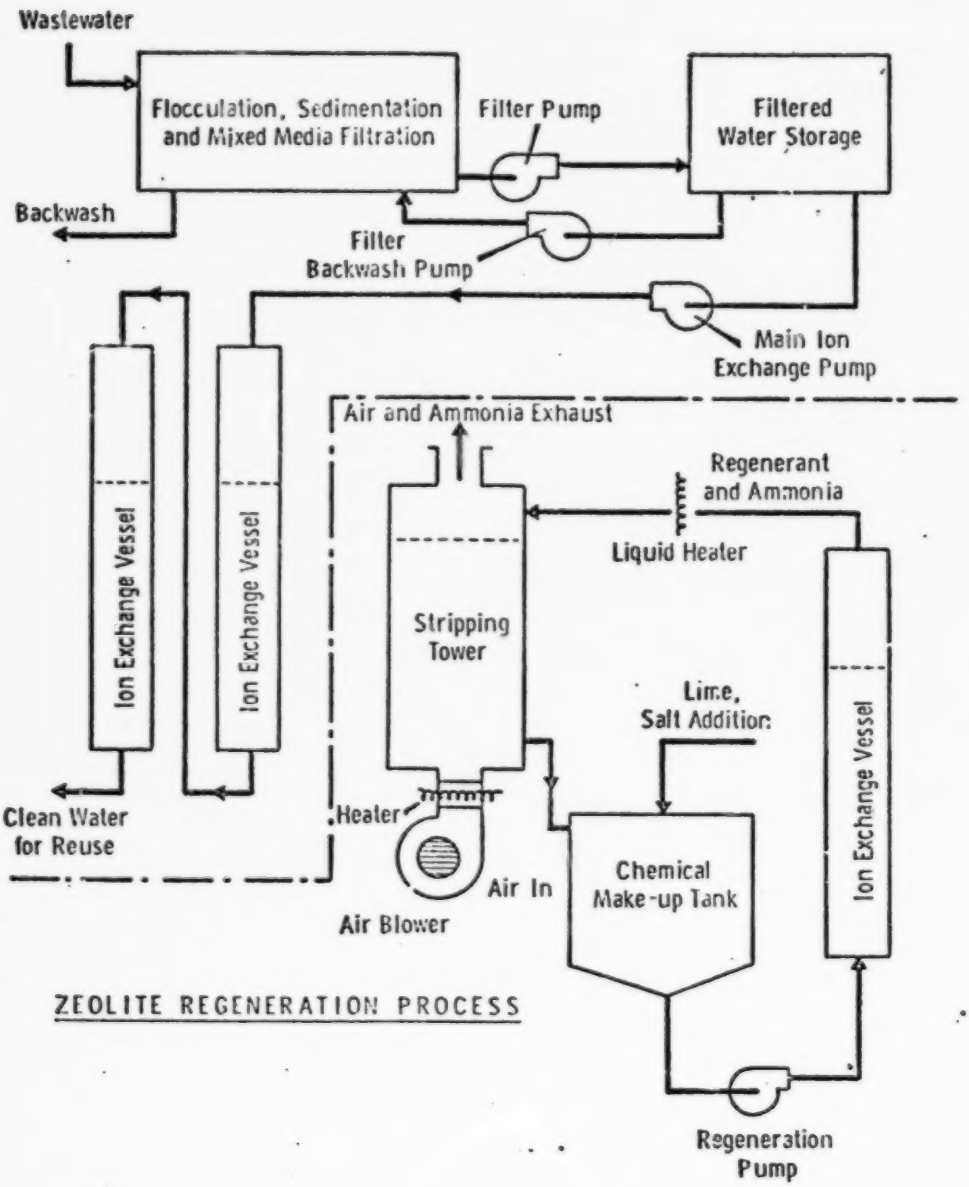


FIGURE 10

FILTRATION AND ION EXCHANGE



ZEOLITE REGENERATION PROCESS